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Emergence and growth performance of *Bolboschoenus planiculmis* varied in response to water level and soil planting depth: Implications for wetland restoration using tuber transplantation

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ABSTRACT

As a common plant in the Momoge National Nature Reserve (MNNR), China, *Bolboschoenus planiculmis* has been acknowledged as a key species in Siberian Crane (*Grus leucogeranus*) habitat by providing food for this migratory waterfowl. Water shortage and salinization have severely impacted *B. planiculmis* vegetation in this area. In order to restore the degraded *B. planiculmis* wetlands, tuber transplantation is tentatively used in MNNR. However, the effects of the abiotic factors on tuber emergence and growth of *B. planiculmis* are poorly understood. In this study, emergence, growth, biomass accumulation and tuber reproduction were investigated experimentally using four water levels (5 cm below soil surface, 0 cm, 10 cm and 20 cm above soil surface) and three soil planting depths (5 cm, 10 cm and 15 cm). Results indicated that emergence, growth and production were closely related with the water level and planting depth. Increasing the water level and planting depth generally decreased the emergence rate and speed of planted tubers. The water table at 5 cm below soil surface significantly increased emergence rate and emergence speed of tubers planted at 5 cm soil depth. Water table at soil surface and 10 cm above soil surface facilitated subsequent growth, biomass accumulation and tuber reproduction of *B. planiculmis* at soil depth of 5 cm. In addition, planting tubers at this depth increased root/shoot ratio across the four water levels. Therefore, the tuber transplanting method can be selectively ameliorated to promote the plant establishment, plant growth and productivity of *B. planiculmis*. Results of this study provide technical support for the restoration of *B. planiculmis* wetland and the improvement in the quality of Siberian Crane habitat.

1. Introduction

Vegetative propagules, such as fragmented stems, rhizomes, and tubers are specialized as storage organs that enable plant populations to survive in unfavorable conditions (van Wijk, 1989). Many aquatic plants recolonize large areas by means of asexual propagules (Grace, 1993; Spencer and Ksander, 2001; Zhou and Wang, 2012), whereas seed propagation contributes relatively little to spread during the initial period because of a poor percentage of germination coupled with a high rate of mortality of juvenile seedlings in the new environments (Eriksson, 1989; Boose and Holt, 1999; Baskin et al., 2000; Li et al., 2013). Planting propagules commonly results in higher survivorship during the first growing season, thus transplanting dominant vegetation types into a restoring site can accelerate succession processes (Zedler, 1992). Monitoring the propagule emergence and growth performance throughout the whole growing season is critical event for predicting the persistence, spread and distribution of aquatic plants.

It is well-known that water depth has a crucial influence on the emergence, establishment, growth and regenerative strategies of plants through changing underwater light conditions, oxygen and nutrients content (Combroux and Bornette, 2004; Elsey-Quirk et al., 2009; Hussner et al., 2009). Specially, water depth greatly affects the biomass production, succession and species composition of establishing plants (Lieffervs and Shay, 1981; Casanova and Brock, 2000). In addition, influence of sediment burial on the survivorship and growth of many aquatic species is widely reported (Brown, 1997; Cabaço et al., 2008). Burial changes light, temperature and water conditions (Brown, 1997), and consequently restrain shoot emergence (Yu et al., 2004). In turn, aquatic plants adapt to burial through reducing the photosynthetic capacity and gas exchange, or shifting biomass allocation (Brown, 1997). The root/shoot ratio of plants is significantly increased with increasing burial depth (Dong et al., 2011). Deeper burial greatly decreases the emergence and survivorship of vegetative propagules (Shen et al., 2005). Although the existing studies have assessed the effect of

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waterlogging or burial on plant growth and development, the interactive effects of these two limiting factors have been paid less attention (Walls et al., 2005, Pan et al., 2012).

Bolboschoenus planiculmis is a perennial clonal plant in the Momog wetland located in Jilin Province, Songnen Plain, China. It reproduces both sexually through seed and asexually through vegetative propagules. The *B. planiculmis* wetlands are important habitats for the migratory Siberian Crane (*Grus leucogeranus*) and *B. planiculmis* tubers are a main food resource for this species. In the past decades, the *B. planiculmis* wetlands ecosystems are rapidly reducing their extent because of the interference of climate change and human activities, such as uneven distribution of water and severe salinization of soil (Wang et al., 2002; Yang et al., 2010; Wen et al., 2012), threatening the persistence of Siberian Crane habitat. To cope with this problem, the Momoge National Nature Reserve (MNNR) recently attempts to carry out restoration practices by mean of tuber transplanting. Understanding the effect of main abiotic factors on the establishment and growth of *B. planiculmis* is of importance to develop restoration techniques. Thus, objective of this study was to determine the effects of water level and soil planting depth on the emergence and growth of *B. planiculmis* tubers throughout the whole growing season, as this is essential knowledge for the technical support of an integrated restoration program.

2. Materials and methods

2.1. Plant and soil materials

Both plant and soil materials used in the study were collected from Ertou wetland (45′53′N; 123°38′E) located in the buffer zone of MNNR. Rainfall and return flow of paddy fields are the main water sources in this area (Jiang et al., 2015). In recent years, the MNNR has started to restore more than 200 ha of *B. planiculmis* wetland in this area by means of tuber transplantation, to provide adequate food and suitable habitat for Siberian crane.

In April 2016, *B. planiculmis* tubers were dug out within 30 cm soil depth and rinsed by tap water. The fibrous roots and rhizomes were removed, and then the tubers were stored in a moist and dark condition at 4℃ prior to the experiment. Simultaneously, the surface soil (30 cm depth) was collected for use in the experiment. The soil type belongs to meadow bog soil with pH of 8.50, electrical conductivity of 577 $\mu S\ cm^{-1}$, organic matter content of 18.4 g kg^{-1}, total nitrogen content of 0.95 g kg^{-1}, and total phosphorus content of 0.26 g kg^{-1}, respectively. The soil was air-dried and sieved through 2 mm sieve before use.

2.2. Experimental design

A split-plot design was employed in this study. The water level was the whole plot factor and the planting depth in soil was the subplot factor. There were four water level treatments (-5 cm below the soil surface, 0 cm, 10 cm and 20 cm above soil surface) and three planting depth treatments (5 cm, 10 cm and 15 cm). A total of 16 plastic tanks (100 cm length × 80 cm width × 60 cm depth) were used and divided into four groups. Each group of tanks was assigned to a water level, and each tank contained three plastic pots. The three pots within each tank were assigned to one of three planting depths. Each pot (20 cm diameter × 30 cm depth) had a hole (1 cm diameter) at the center of bottom and was filled with collected soil. Within each pot, thirty uniform *B. planiculmis* tubers (mean dry weight 1.3 g) were planted in either at 5 cm, 10 cm or 15 cm soil depth, according to the subplot level assigned. The water levels were maintained by daily addition of tap water. All the tanks containing pots were placed in a greenhouse (average temperature ranged from 20 to 25 °C and the relative humidity 60 to 70%) located in the research site of Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences (Changchun City, Jilin Province). The experiment began on 1 May 2016 and ended on 1 August 2016 (lasted for 14 weeks).

2.3. Plant growth measurements

Seedling emergence was recorded every two weeks since planting. In the study, emergence was considered as the appearance of tuber sprouts 1 cm above the soil surface. After 14 weeks since planting, plant height was measured from the soil surface to the tip of the stem. All the plants in each pot were harvested at the soil surface level. The belowground parts were cleaned up by tap water, and fractioned into fibrous roots and rhizomes. The number of new tuber was then recorded. All plant samples were oven dried at 90 °C for one hour, and subsequently at 65℃ to constant weight.

2.4. Data analysis

To determine the effects of water level and planting depth and their interactions on the emergence rate and speed of *B. planiculmis* tuber, and plant growth properties, the data were analyzed by split-plot ANOVA with water level as a plot factor and planting depth as a subplot factor at $p < 0.05$ level. Differences between the means were compared using LSD tests at $p < 0.05$ level. All analyses were conducted with SPSS software version 18.0 (SPSS, Chicago, IL, USA).

The root/shoot ratio (RSR) was calculated by dividing belowground (including the tubers, fibrous roots and rhizomes) dry weight by the combined dry weight of all the aboveground plant fractions in each pot. The emergence rate was calculated as the number of tuber sprouts as a percentage of the total planted tubers in each pot. Emergence speed was calculated according to a modification of the germination vigor index described in previous studies (Maguire, 1962; Morris and Schupp, 2009), where biweekly emergence was divided by the number of 2-week intervals since the beginning of the experiment. The higher emergence speed means that the tuber sprout emerges more quickly, whereas the lower emergence speed means the tubers take longer time to emerge. Thus, emergence speed is mathematically described as follows:

$$\sum_{w}^{n=1} g/w$$

where *g* is the emergence rate each 2-week and *w* is the number of 2-weeks intervals since the beginning of the experiment.

3. Results

The emergence of *B. planiculmis* tubers planted was significantly affected by water level, soil planting depth and their interactions ($p < 0.001$; Table 1). The emergence rate was highest at water table of 5 cm below soil surface (-5 cm) when the tubers were planted at soil planting depth of 5 cm ($p < 0.05$; Fig. 1a), and it decreased markedly with increasing planting depth ($p < 0.05$). However, there was no significant difference in emergence rates of planted tubers among three planting depths when they were planted in water table at soil surface ($p > 0.05$). Although the tubers were able to emerge at water table of 10 cm above soil surface when planted at 5 cm and 10 cm soil, no seedling was observed at soil depth of 15 cm. A large proportion of tubers were unable to emergence at water depth of 20 cm, and only few seedlings were observed at 5 cm soil depth (emergence rate of 6.7%). Similarly, the water table of 5 cm below soil surface accelerated emergence speed *B. planiculmis* tuber at 5 cm planting depth (Fig. 1b). And, the emergence speed was generally reduced with increasing planting depth when the water tables were 5 cm below soil surface and at soil surface.

Water level and soil planting depth significantly affected plant height, biomass production and new tuber production ($p < 0.001$; Table 1). The water table at 5 cm below soil surface increased the plant